Research on Reliability Optimization Design of Mechanical Structure Based on Computational Intelligence

Xinyu Feng*
Xijing Zhu
Xiangmeng Li

In order to extend the actual service life of mechanical equipment components and realize the reasonable protection of applied structural components, the reliability optimization design of mechanical structure based on computational intelligence is studied. With the help of wavelet neural network, the established reliability and reliability index are obtained, and then the basic theory of reliability and computational intelligence technology are studied through the reliability optimization of mechanical zero structure. On this basis, the application concepts of reliability design method are defined, and the final calculation result of reliability optimization value is obtained by combining fuzzy set and level cut set, so as to realize the reliability optimization design of mechanical structure based on computational intelligence. The experimental results show that, compared with the traditional design method, the optimization design method supported by computational intelligence technology can better improve the disadvantages of mechanical structure object, and has strong practical application value in extending the reliability application time.

Keyword：computational intelligence；mechanical structure；reliability optimization；

***Tob Regul Sci.*™ 2021;7(5):1304-1310**

DOI: doi.org/10.18001/TRS.7.5.47

INTRODUCTION

Computational intelligence is just an empirical computer thinking program, which is a branch of artificial intelligence system. It is a system with independent thinking ability to assist human beings to deal with all kinds of problems. The intelligence of the system is constantly enhanced, and the complexity of the tasks automatically and entrusted by the computer is increasing. Intelligent computing has been fully put into our industrial production and life. Computational intelligence is inspired by the laws of the biological world of nature, according to its principles to imitate and design algorithms to solve problems [1-2]. This technology uses advanced it and CT technologies (chip, architecture, AI, etc.) to realize the intelligent upgrade of IT infrastructure (intelligent management, online upgrade and evolution), intelligently allocate the optimal computing resources for different business loads, improve the utilization efficiency of IT infrastructure, and optimize the computing TCO of current business; secondly, facing the new business form of AI in the future, it provides abundant and economic computing resources In

addition, it can develop, deploy, use and collaborate anytime and anywhere, reduce the threshold of AI use, and make AI a universal and inclusive computing resource; finally, it is an open architecture and ecology, so that more participants have the opportunity to participate.

Mechanical design is an important part of mechanical engineering, is the first step of mechanical production, is the most important factor to determine the mechanical performance. The goal of mechanical design is to design the best machine under various limited conditions (such as materials, processing capacity, theoretical knowledge and calculation means), that is, to make the optimal design. Optimization design needs to consider many requirements, such as the best working performance, the lowest manufacturing cost, the smallest size and weight, the most reliable in use, the lowest consumption and the least environmental pollution. These requirements are

Xinyu Feng School of Mechanical Engineering,North University of China, Taiyuan, 030051,China, Xijing Zhu School of Mechanical Engineering,North University of China, Taiyuan, 030051,China Xiangmeng Li School of Mechanical Engineering,North University of China, Taiyuan, 030051,China, *Corresponding author: School of Mechanical Engineering,North University of China, Taiyuan, 030051,China(E-mail:fengxinyu2017@nuc.edu.cn)*

often contradictory, and their relative importance varies with different types of machinery and applications [3-4]. The designer's task is to balance the weight according to the specific situation, make overall plans, and make the designed machinery

have the best comprehensive technical and economic effect. In the past, the optimization of design mainly depended on the knowledge, experience and foresight of designers. With the development of basic theory of mechanical engineering, value engineering, system analysis and other new disciplines, the accumulation of technical and economic data for manufacturing and use, and the popularization and application of computer, optimization gradually abandons subjective judgment and relies on scientific calculation.

BASIC THEORY OF RELIABILITY AND COMPUTATIONAL INTELLIGENCE TECHNOLOGY

Wavelet Neural Network

The basic idea of wavelet transform is similar to Fourier transform, that is, the signal is represented by the projection of the signal on the space formed by a cluster of basis functions. Usually, Fourier transform expands the signal according to triangular sine and cosine basis, and represents any function as a linear superposition of harmonic functions with different frequencies, which can better describe the frequency characteristics of the signal. Due to its own characteristics, Fourier transform has no resolution in time or space domain, so it can’t be analyzed locally, which brings many applications Insufficient. Wavelet transform has good localization performance in both time domain and frequency domain. It has a flexible time and frequency window. Some people call it a mathematical "microscope", so it is of great significance in theory and practical application [5-6].

Wavelet transform has time-frequency local characteristics and zoom characteristics, while neural network has self-learning, adaptive, robustness, fault tolerance and generalization ability. How to combine the advantages of the two has always been a concern. In the case of wavelet analysis, the signal is divided into two kinds of feature space extraction, which are wavelet pre-processing and neural network feature extraction; The other form is to replace the neurons in the neural network with wavelet function, which organically combines the wavelet transform and neural network, thus inheriting the advantages of the two, forming a wavelet neural network or wavelet network [7].Assuming φ is the constant coefficient of wavelet transform, e is an undefined parameter of mechanical structure coefficient, combining the above physical quantities, the existence condition of wavelet neural network can be defined as:

$$W = \sum_{-\infty}^{+\infty} \frac{|\varphi(e)|}{|\overline{w}|^2} de \quad (1)$$

In the formula, $\overline{w}$ represents the mean value condition of reliability optimization of mechanical structure equipment by computational intelligence theory.

Reliability and Reliability Index

In engineering practice, it is difficult to have enough data to determine the probability density function or joint probability density function of the basic random variable vector needed to calculate the reliability. Even if the probability distribution can be approximately specified, it is difficult to obtain the reliability by integral calculation in most cases, and the numerical integration is often not practical, so other approximate methods are generally used. Because the central point method has some shortcomings, that is, if the probability distribution of basic variables is non normal distribution or non logarithmic distribution, the calculation results of structural reliability are quite different from the actual situation [8]. In addition, the limit state function is expanded into Taylor series near the mean value point and linearized. The higher order terms of the nonlinear function are omitted, resulting in the error increasing with the increase of the distance from the linearization point to the failure boundary. Aiming at the above problems of the first-order second moment center point, people begin to seek the linear optimization point on the failure boundary. The selected point is usually the design checking point corresponding to the maximum possible failure probability of the structure, so as to overcome the problems of the mean first-order second moment method. This method is no doubt better than the mean first order second moment method, but it is accurate only under the condition of statistical independence of random variables, normal distribution and linear limit state equation, otherwise only approximate results can be obtained.

In the actual process of mechanical structure design, many design parameters of mechanical structure are uncertain due to the uncertainty of lots of information. In addition, due to the variability of engineering material properties and errors in manufacturing and installation, the mechanical structure parameters are also uncertain [9-10]. It can be seen that the uncertainty of design information and parameters of mechanical structure is inherent in practical engineering problems, and has a significant impact on the characteristics of mechanical structure system. Especially when the design data and structural parameters are quite different, it is more necessary to consider the influence of uncertain factors in the modeling, analysis and design stages.

Reliability Optimization of Mechanical Parts Structure

Sometimes, mechanical reliability design is not equal to optimization design. Although reliability design can determine or predict the completion probability of the designed structural product and ensure the realization of the reliability index of the product under the specified service conditions and within the specified service time, it can't guarantee that the product has the best working performance and parameter matching, the smallest structural size and quality, and the most reliable design On the other hand, mechanical optimization design does not include reliability design [11]. Therefore, in order to make products have both reliability requirements and optimal design results, it is necessary to combine reliability design theory with optimization technology, that is, to adopt reliability optimization design method. According to this method, not only the reliability of the product in use can be given quantitatively, but also the optimal solution of parameters in function, parameter matching, structure size and quality, cost and so on can be obtained. For the reliability optimization design of mechanical parts, there are narrow sense and broad sense [12-13]. To maximize the reliability of components, the constraint condition is the cost of components, and the objective function is the reliability of components, the mathematical model can be expressed as follows:

$$F = \frac{W \times \Delta U}{\chi \cdot \hat{p}} \quad (2)$$

In the above formula, ΔU represents the variation of mechanical structure design application per unit time, χ represents the reliability optimization design coefficient, and $\hat{p}$ represents the value of mechanical structure reliability disposal authority based on computational intelligence.

RELIABILITY OPTIMIZATION DESIGN OF MECHANICAL STRUCTURE BASED ON COMPUTATIONAL INTELLIGENCE

Concept of Reliability Design Method

If a mechanical structure system is robust to uncertainty, it has strong anti-interference ability and high reliability. On the contrary, if the reliability of mechanical structure system is high, then its anti-interference ability is strong and robustness is good. It can be seen that in the process of product design, reliability design and robust design play an important role in improving product quality and maintaining the stability of product performance, and they are consistent in essence [14-15]. But in practical application, the design methods and requirements of the two are quite different. Reliability design uses reliability theory to deal with uncertainty. Through reasonable design, it can meet certain reliability requirements. Robust design is to make the designed product insensitive to the changes of design variables, that is, it can resist a certain degree of unexpected uncertainty interference. Therefore, it is very meaningful to combine reliability design theory with robust design method to develop a new engineering design method. Any kind of mechanical structure, its reliability will be affected by some factors, either eliminate these factors as far as possible, or reduce the influence of these factors as far as possible. In practical engineering, it is often difficult to eliminate these factors, even if it can be eliminated, it will cost a lot of money, so this method is not the first choice. However, it is relatively easy and low-cost to reduce the influence of these factors, that is, the reliability of mechanical structure is not very sensitive to the changes of these factors [16]. In fact, if a design parameter has a great influence on the reliability of mechanical structure, the quantitative value of its reliability sensitivity will be larger, that is, the more sensitive; on the contrary, if the influence of a design parameter on the reliability of mechanical structure is not significant, the quantitative value of its reliability sensitivity will be smaller, that is, the more robust.

Fuzzy Sets and Level Cut Sets

The basic idea of reliability robust optimization design is: Based on the reliability optimization design model, the reliability sensitivity is added to the objective function, and the reliability robust design is reduced to a multi-objective optimization problem satisfying the reliability requirements by using the multi-objective optimization strategy. Because the reliability robust design of mechanical structure components requires that the reliability is not sensitive to the changes of design parameters, the problem of reliability robust design is transformed into multi-objective optimization design for processing [17-18].

Since there is no unique global optimal solution to the multi-objective optimization problem, solving the multi-objective optimization problem is actually to find an optimal solution set. The traditional multi-objective optimization method transforms the multi-objective problem into a single objective problem by weighted sum. This method requires a strong prior understanding of the problem itself, and is difficult to deal with many objective optimization problems.

Evolutionary computing is a computing technology based on population operation, and multiple solutions can be searched in parallel, and it can use the similarity between different solutions to improve its concurrent solving ability. Therefore, evolutionary computation is more suitable for solving multi-objective optimization problems [19-20].

Assuming that E represents the robust index parameter related to the reliability of mechanical structure components. The simultaneous formula (2) defines the expressions of fuzzy set and level cut set as follows:

$$M = \left\{ n \frac{Fd_n^{\ 2}}{E} \beta l \right\} \quad (3)$$

Among the formula, n represents the constant calculation term, d_n represents the reliability design factor when the constant term is equal to n, β represents the given optimization processing authority, and l represents the idealized processing factor condition.

Numerical Calculation of Reliability Optimization

In order to improve the calculation accuracy of reliability, based on the first-order second moment method, people try the higher-order higher-order moment method of reliability, and put forward the second-order second moment method and the fourth-order moment method respectively. Its principle is the same as that of the first-order second moment method. When calculating the reliability index, it is based on obtaining the partial derivative of the limit state equation and its Taylor series. The calculation accuracy is high, but it is difficult to deal with some complex and difficult derivative function [21-22].

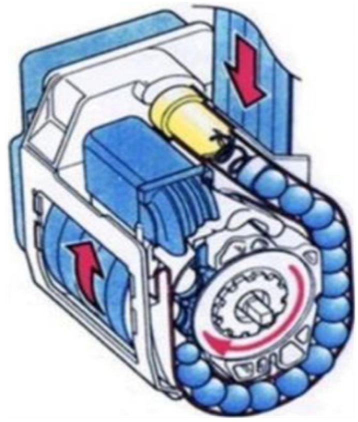
In a finite field of the failure surface, the failure point is selected according to a certain principle, and the distance from the origin to the failure point is regarded as the function of the coordinate vector of the failure point in the original coordinate system. The function is shown graphically to find the minimum value. According to the principle, the minimum value of geometric reliability is the minimum value. The larger the finite field, the smaller the probability of losing the design checking point. According to the properties and utility of design variables in function, they can be divided into resistance variables, action effect variables and dynamic variables. The resistance variable makes the structure tend to be safe and reliable, the action utility variable makes the structure tend to be dangerous and invalid, and the increase of the dynamic variable may make the function increase or decrease, that is, the function is not a monotonic function of the dynamic variable, so the utility of the dynamic variable is not easy to determine [23-24]. For structural reliability problems, the values of design variables at design checking points are generally positive, and the resistance variable is less than its mean value, the action utility variable is greater than its mean value, while the dynamic variable is not easy to determine. The drawing space can be initially determined according to the attributes of each design variable. In order to increase the probability of obtaining the design checking point, the initial space should be larger. The denser the drawing points are, the greater the probability of obtaining the design checking points is.

From the mathematical point of view, the uncertain factors in mechanical structure can be roughly divided into three categories: (1) Randomness; (2) Fuzziness; (3) Certainty. Due to the insufficient conditions of the event, there is no inevitable causal relationship between the condition and the result, which leads to the uncertainty of the event. This uncertainty is called randomness. The mathematical methods often used to solve the problem of randomness are probability theory, mathematical statistics and random process theory; Fuzziness is a kind of objective attribute that the concept of things themselves is not clear, there is no exact definition in essence, and there is no definite limit in quantity. The main mathematical method to study and deal with fuzziness is fuzzy mathematics; unascertained refers to the uncertainty caused by the incompleteness and incompleteness of information and data. At present, the relatively mature research is engineering randomness [25].

COMPARATIVE EXPERIMENTAL ANALYSIS

In order to verify the practical application value of the reliability optimization design scheme of intelligent mechanical structure based on calculation, the following comparative experiments are designed. The mechanical structure equipment components as shown in Figure 1 are selected as the experimental objects. The established experimental software is used to record the relevant experimental index values, and these data information are input into the control host of the experimental group and the control group respectively. The host of the experimental group is equipped with the reliability optimization design scheme based on Computational Intelligence mechanical structure, while the host of the control group is equipped with the traditional design method, in the same experimental environment To analyze the real-time changes of each index value.

Figure1
Experimental mechanical structure equipment components



It is known that WEI index and SEI index can reflect the actual protection ability of the method used for mechanical structure equipment. Generally, the larger the WEI index and SEI index, the stronger the actual protection ability of the method used for mechanical structure equipment, and vice versa. The Table 1 records the specific numerical changes of the experimental group and the control group.

Table 1
Comparison of Wei indicators

The experimental time / (min)	WEI index value	
	The experimental group	The control group
5	0.84	0.37
10	0.87	0.37
15	0.89	0.37
20	0.90	0.37
25	0.91	0.35
30	0.92	0.34
35	0.93	0.33
40	0.94	0.32
45	0.95	0.31
50	0.96	0.30

According to the Table 1, it can be seen that with the extension of the experimental time, the WEI index value of the experimental group kept rising, and the global maximum value reached 0.96. The WEI index of the control group began to decline after a period of stable state, and the global maximum value was only 0.37, which decreased by 0.59 compared with the maximum value of the experimental group. In conclusion, the application of the reliability optimization design scheme of intelligent mechanical structure based on calculation can promote the rising trend of Wei index, and can better extend the actual service life of mechanical equipment components.

Table 2
Comparison of SEI indexes

The experimental time / (min)	SEI index value	
	The experimental group	The control group
5	0.53	0.14
10	0.53	0.17
15	0.56	0.20
20	0.56	0.22
25	0.59	0.24
30	0.59	0.26
35	0.62	0.28
40	0.62	0.29
45	0.65	0.29
50	0.65	0.29

According to the analysis of Table 2, with the extension of experimental time, the index of SEI in the experimental group always kept a ladder like rising trend, and the maximum value in the whole experimental process reached 0.65. The SEI index of the control group began to stabilize after a slight increase, and the maximum value in the whole experiment process only reached 0.29, which decreased by 0.36 compared with the maximum value of the experimental group. To sum up, after the application of the reliability optimization design scheme of intelligent mechanical structure based on calculation, the SEI index value also shows a significant upward trend, which can better guarantee the actual service life of mechanical equipment components.

CONCLUSION

Compared with the traditional design method, the reliability optimization design scheme of computational intelligent mechanical structure realizes the reliability optimization processing of mechanical parts structure under the effect of wavelet neural network, and can obtain accurate numerical calculation results of reliability optimization. From the practical point of view, the WEI index and SEI index show an obvious upward trend. It can extend the actual service life of mechanical equipment components and realize the reasonable protection of applied structural components.

REFERENCE

1. Jang G H , Ahn J H , Kim B O , et al. Design and Characteristic Analysis of a High-Speed Permanent Magnet Synchronous Motor Considering the Mechanical Structure for High-Speed and High-Head Centrifugal Pumps[J]. IEEE Transactions on Magnetics, 2018, 54(11):1-6.
2. Dai M , Deng J , Jiang H , et al. Numerical investigations on the mechanical properties of metallic hollow spheres structure with perforations under compression[J]. Materialwissenschaft und Werkstofftechnik, 2020, 51(4):488-499.
3. Cirulli M , Kaur A , Lewis J E M , et al. Rotaxane-Based Transition Metal Complexes: Effect of the Mechanical Bond on Structure and Electronic Properties[J]. Journal of the American Chemical Society, 2019, 141(2):879-889.
4. Rahaman M Z , Akther Hossain, A. K. M. Effect of metal doping on the visible light absorption, electronic structure and mechanical properties of non-toxic metal halide CsGeCl 3[J]. Rsc Advances, 2018, 8(58):33010-33018.
5. Montenero G , Auchmann B , Brouwer L , et al. Mechanical Structure for the PSI Canted-Cosine-Theta (CCT) Magnet Program[J]. IEEE Transactions on Applied Superconductivity, 2018, 28(3):1-5.
6. Malkin A I , Klyuev V A , Ryazantseva A A , et al. The Development of the Structure, Morphology, and Fractional Composition of "Al2B" Composite Powders in the Course of Mechanical Activation[J]. Colloid Journal, 2019, 81(6):703-710.
7. Kostina M V , Kostina V S , Muradyan S O . Effect of a Thermomechanical Action on the Structure and the Mechanical Properties of the Welded Joints of a Hot-Rolled Austenitic Nitrogen-Bearing Steel[J]. Russian Metallurgy (Metally), 2019, 2019(1):36-41.
8. Volkova E F , Akinina M V , Mostyaev I V , et al. Effect of Small Lanthanum Additions on the Structure, the Phase Composition, and the Mechanical Properties of a Magnesium ML5pch Alloy in the As-Cast and Heat-Treated States[J]. Russian Metallurgy (Metally), 2020, 2020(3):187-192.
9. Savvova O V , Topchyi V L , Babich O V , et al. Effect of the Structure of Lithium-Silicate Glasses on the Mechanical Properties of Transparent Glass-Ceramic Materials[J]. Strength of Materials, 2019, 50(6):1-6.
10. Prokopiv M M , Kharchenko O V . Features of Influence of Sintering Conditions of Fine-Grained WC—10Co Cemented Carbide on Its Structure, Physical-Mechanical and Operational Characteristics[J]. Journal of Superhard Materials, 2019, 41(2):106–113.
11. Abd-Elwahed M S , Wagih A , Najjar I M R . Correlation between micro/nano-structure, mechanical and tribological properties of copper-zirconia nanocomposites[J]. Ceramics International, 2020, 46(1):56-65.
12. A X J , B Z C , B X T , et al. Reconstruction of meso-structure and numerical simulations of the mechanical behavior of three-dimensional four-directional braided ceramic matrix composites[J]. Ceramics International, 2020, 46(18):29309-29320.
13. Aripov G R , Bazlov A I , Churyumov A Y , et al. Study of the Change in the Structure and Properties of High-Entropic Alloys during Thermal and Thermomechanical Processing[J]. Russian Journal of Non-Ferrous Metals, 2020, 61(4):413-420.
14. Gu X , Yang L , Ma X , et al. Ta addition effects on the structure, mechanical and thermal properties of sputtered Hf-Ta-C film[J]. Ceramics International, 2019, 45(12):15596-15602.
15. Blinov V M , Kostina M V , Lukin E I , et al. Effect of Heat Treatment on the Structure and the Mechanical Properties of a Low-Alloy 10Kh3A Steel with an Overequilibrium Nitrogen Content[J]. Russian Metallurgy (Metally), 2020, 2020(4):422-425.
16. Terent'Ev V F , Blinova E N , Seval'Neva T G , et al. Effect of the Tempering Temperature on the Structure and the Mechanical Behavior of VNS9-Sh TRIP Steel with a High Martensite Content[J]. Russian Metallurgy (Metally), 2020, 2020(4):408-415.
17. Wang, Yu, Wen, et al. Understanding the Mechanical Properties and Structure Transition of Antheraea pernyi Silk Fiber Induced by Its Contraction[J]. Biomacromolecules, 2018, 19(6):1999-2006.
18. Bannykh O A , Sorokin A M , Bannykh I O , et al. Structure and Mechanical Properties of High-Strength Structural Steels[J]. Russian Metallurgy (Metally), 2018, 2018(6):528-532.
19. Wu J , Luo B , Liu X , et al. Control of the structure and mechanical property of porous WS 2 scaffold during freeze casting[J]. Journal of Porous Materials, 2018, 25(1):37-43.
20. Colombani O , Barioz C , Bouteiller L , et al. Attempt toward 1D Cross - Linked Thermoplastic Elastomers: Structure and Mechanical Properties of a New System[J]. Macromolecules, 2018, 38(5):1752-1759.
21. Slawomir B , Grz?bka-Zasadzińska Aleksandra, Majka O , et al. The effect of chemical modification of wood in ionic liquids on the supermolecular structure and mechanical properties of wood/polypropylene composites[J]. Cellulose, 2018, 25(8):4639-4652.
22. Shah A , Ali Z , Mehmood S , et al. Electronic Structure,

Mechanical and Magnetic Properties of the Quaternary Perovskites CaA 3 V 4 O 12 (A=Mn, Fe, Co, Ni and Cu)[J]. Journal of Electronic Materials, 2020, 49(2):1230-1242.
23. Terent'Ev V F , Ashmarin A A , Blinova E N , et al. Mechanical Properties and Structure of a VNS9-Sh Steel as Functions of the Tempering Temperature[J]. Russian Metallurgy (Metally), 2019, 2019(4):403-408.
24. Wang Y , Liu Q , Zhang B , et al. Controlling the structure and mechanical properties of porous B 4 C ceramics with unidirectionally aligned channels using sintering additives[J]. Ceramics International, 2020, 46(10):17117-17121.
25. Dubov A , Dubov A , Marchenkov A , et al. Study of the structure and mechanical properties of engineering products made of austenitic-martensitic steel, using the metal magnetic memory technique[J]. Welding in the World, 2020, 64(11):1887-1895.